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Fuel-price reform to achieve climate and energy policy goals in Saudi Arabia: A multiple-scenario analysis

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ABSTRACT

Saudi Arabia experiences annual growth of 6% in its power demand. Generation expansion has been driven by low domestic retail fuel prices leading to a power generation mix based on fossil fuels only. In light of current climate change discussions, this research assesses future generation expansion under different potential fuel-price reforms by an enhanced OSeMOSYS model. Results demonstrate that domestic retail fuel price levels > 20% [> 60%] of expected international wholesale fuel prices[1] are necessary to minimize emissions when considering emissions penalties [without pricing for emissions]. By 2030 renewables can reach 70% penetration by capacity and 30% by energy.

1. Introduction

With about one-fifth of the world's proven oil reserves, the Kingdom of Saudi Arabia (KSA) is endowed with energy resources and is the largest oil exporter in the Organization of Petroleum Exporting Countries (OPEC) (OPEC, 2016). The country also holds the world's sixth largest proven gas reserves (BP, 2014), has abundant solar (Farnoosh et al., 2014) and wind (Alyousef and Stevens, 2011) energy resource potential, and is the world's 13th largest producer and consumer of electricity (The World Factbook, 2017). As a result of low oil and gas prices over the last two years, several countries in the Middle East (including the United Arab Emirates, Oman, Bahrain, and the KSA) have increased their domestic energy prices since the beginning of 2016 (Mills, 2016). This is one of several measures taken by these countries to cope with the loss of revenues from oil and gas sales. It follows examples such as Jordan, Morocco, and Egypt that already implemented energy price adjustments in previous years.

The KSA has experienced remarkable growth in demand for power in the last decade (SEC, 2014) driven by multiple factors, including population growth, robust economic development, improvement in standards of living, harsh weather conditions, industrial development, economic policies geared toward diversification into energy-intensive industries, and low energy pricing regimes that encourage lavish consumption (Fattouh, 2013, Woertz, 2013). Peak electricity demand has grown by 6.1% per year since 2003. Peak demand reached 56.5 GW in 2014 and annual electricity demand amounted to 274.5 TWh in the same year.

To meet this increased demand, a substantial amount of power generation infrastructure has been added over the last years. Until now, almost 100% of power generation is based on the domestic fossil fuel sources of oil and gas (Farnoosh et al., 2014), apart from decentralized photovoltaic applications in Dhahran (10.5 MW and 0.035 MW), Tabuk (1 MW), Riyadh (5.3 MW and 0.2 MW), Jiddah (5.4 MW), on Farasan Island (0.5 MW) and at the King Abdullah University of Science and Technology (2 MW). The major reason for the sole utilization of fossil fuel resources lies in the domestic fuel pricing policies that keep prices well below international levels (Alyousef and Stevens, 2011, OIES, 2015). This hinders the society's awareness of energy efficiency (Gately et al., 2012), makes investment into renewables financially unattractive, and contributes to a growing cumulative carbon dioxide emissions level (Mansouri et al., 2013). At present, low prices for gas, diesel, gasoline, and power turned the world's 20th biggest economy into its 6th biggest consumer of oil (Reuters, 2013). However, growing concerns about climate change have become an important factor influencing energy policies in the Middle East and North Africa (MENA) (Griffiths, 2017) and were elevated by the COP21 Paris Agreement, which was ratified by the KSA (UNFCCC, 2016). This research examines the Kingdom's commitment to addressing climate challenges and develops a fuel-price ratio based on international fuel-price expectations.

We contribute to the research in the field of fuel-price liberalization by using actual costs for renewable and conventional generation technologies to show which price levels will trigger an energy exporting

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[1] The international wholesale fuel price provides a proxy for future costs as well as an upper limit as it represents the highest expected fuel price for imported fuels.

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Nomenclature

CC	Combined Cycle (or Combined Cycle Gas Turbine)
CSP	Concentrated Solar Power
COP	Conference of the Parties, e.g., COP21 in Paris
CO_2	Carbon dioxide
EIA	U.S. Energy Information Administration
ELCC	Expected Load Carrying Capability
EROI	Energy Return on Energy Investment
FOM	Fixed Operational and Maintenance
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GEP	Generation Expansion Planning
GT	Gas Turbine (or Open Cycle GT)
GW	Gigawatt
HFO	Heavy Fuel Oil
IPP	Independent Power Producer
KSA	Kingdom of Saudi Arabia
kWh	kilowatts per hour
LQER	Lesser Quantity Emissions Rates
MBD	Thousand Barrels per Day
MCDA	Multi-Criteria Decision Analysis
MENA	Middle East & North Africa
MILP	Mixed Integer Linear Programming
MMBTU	Million British Thermal Units
MW	Megawatt
NO_x	Nitrogen oxides
OPEC	Organization of Petroleum Exporting Countries
OSeMOSYS	Open Source energy MOdeling SYStem
PJ	Peta Joule
$PM_{2.5}$	Fine particles with a diameter of 2.5 lm or less
PV	Photovoltaics
QELD	Quality Enhanced Life Days
RES	Renewable Energy Sources (or Renewables)
SAR	Saudi Riyal (1 SAR = US$ 3.75, 1 SAR = 100 Halala)
SEC	Saudi Electricity Company
SO_2	Sulfur dioxide
ST	Steam Turbine
SWF	Sovereign Wealth Fund
TWh	Terawatts per hour
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compounds
VOM	Variable Operation and Maintenance
VR	Vacuum Residue

country's utility sector to diversify its portfolio and reduce the role of fossil fuels.

The structure of the remainder of the paper is as follows: Section 2 offers a comprehensive literature review. Section 3 provides an extensive overview of the utility sector in the KSA. Section 4 reviews the fuel-price liberalization research. Section 5 outlines the modeling approach and describes the scenarios considered. Section 6 illustrates the results and Section 7 concludes. Finally, Section 8 presents possible future research.

2. Literature review

Research exists on power generation expansion planning all over the world (Zhang et al., 2013, Thiam et al., 2012, Fairuz et al., 2013, Walmsley et al., 2014, Habib and Chungpaibulpatana, 2014, Lienert and Lochner, 2012, Aliyu et al., 2013, Wu and Huang, 2014, Shahmohammadi et al., 2015, Chaudry et al., 2014, Becerra-Lopez and Golding, 2008, Brand and Missaoui, 2014), although the future electricity generation development in the KSA under different fuel-price scenarios has not been analyzed. Previous studies related to modeling the KSA power generation expansion planning include (Farnoosh et al., 2014, Mansouri et al., 2013, and Groissböck and Pickl, 2016). The studies of Farnoosh et al. focus on cost optimization in an assumed international wholesale fuel price context (Farnoosh et al., 2014), while Mansouri et al. (2013) deal with CO_2 emissions savings where carbon capture and storage and solar photovoltaic are considered. Groissböck and Pickl (2016) model the KSA's power market retrospectively under both cost and environment considerations for the period 2003 to 2013. The Open Source energy MOdeling SYStem (OSeMOSYS) model framework, developed by renowned KTH Royal Institute of Technology in Stockholm, represents a flexible and comprehensive Mixed Integer Linear Programming (MILP) framework for long-term energy planning that is available on an open source basis (Bazilian et al., 2012). MILP is a commonly used method to assess medium and long-term impacts within power systems of economies of varying sizes and stages of development (Howells et al., 2011, Welsch et al., 2012, Welsch et al., 2014). In its base form, OSeMOSYS provides a test-bed for new energy model developments and system model applications, especially in developing countries. More advanced forms include added functionalities for prioritization of demand types, shifting demand, and storage options (Welsch et al., 2012), as well as reserve requirements and dispatching features (Welsch et al., 2014). Groissböck and Pickl (2016) made model improvements to OSeMOSYS including multi-objective functions (adjustable weights on costs and emissions). OSeMOSYS has been used by other researchers to model the long-term electricity mix in Tunisia (Dhakouani et al., 2017), to assess overall energy security questions (Augutis et al., 2015), to hedge the risk of increased emissions in long-term energy planning (Niet et al., 2017), to model the British Columbia and Alberta electricity systems (English et al., 2017), to address the energy, economy and land use nexus when exploiting bioenergy in developing countries (Gonzales-Salazar et al., 2016), and to estimate the cost of energy access in Timor Leste (Nerini et al., 2015).

The topic of future electricity capacity expansion in the KSA under different price reform scenarios, including the choice of fossil fuel generation versus renewable generation, deserves detailed study since it is of broader policy, industry, and geopolitical interest, not least because of the major role the KSA plays in world oil markets. At times of low oil prices, fuel-price reforms are a major topic of consideration in many countries as budgets of oil-producing nations face increased stress. Indeed, energy subsidies have recently been at the center of research in academia (Griffiths, 2017, Moshiri, 2015, Guillaume and Zytek, 2010, Dartanto, 2013, Krane and Hung, 2016, Fattouh and Sen, 2016, Benes et al., 2015, Lahn, 2016) as well as by the International Monetary Fund (IMF, 2008, 2013, 2015, 2014), the World Bank (World Bank, 2010), and the International Energy Agency (IEA, 2010, 2011). This study: (i) provides a brief overview of the KSA power market with the latest data; (ii) analyzes the impacts of different price-reform scenarios on the future electricity market expansion in terms of renewable penetration and CO_2 reduction to comply with COP21 (and upcoming COP's) agreements; and (iii) improves the OSeMOSYS model framework by implementing a multiple-scenario analysis as well as by including the possibility to allow plant retirements, as today's KSA power plant fleet consists of more than 40% inefficient gas turbines (GT). Temperature correction is incorporated into the model to allow performance and generation output adjustments based on ambient air temperatures (Groissböck and Pickl, 2016).

Specifically, this research investigates the evolving of the power market and the renewable energy penetration in the KSA over the period 2015 to 2030 under different fuel-price reform scenarios in light of recent COP discussions with the goal to reduce CO_2 emissions: i) no price reform; ii) intermediate price reform (annual change by increasing the domestic retail fuel price by 10%–100% (in 10%

increments) up to an international level of 10–100% (in 10% increments) of international wholesale fuel price); and iii) immediate full price reform to international wholesale fuel prices (low, reference, and high international wholesale fuel price forecast). The results are compared with each other to guide policymakers for the benefit of the future development of the KSA electricity market and to provide insights about energy diversification and renewable resource expansion for other heavily subsidized energy-intensive economies in the world.

3. Country background

3.1. Economic parameter

The KSA's population has grown in the last 20 years from 18.6 million in 1995 to 29.4 million in 2014 (UN, 2015). Riyadh, as the capital of the country and the largest city, more than doubled in population from 2.8 to 5.7 million inhabitants. The Pardee Center for International Futures (IFS) expects the KSA's population to grow to between 34.5 and 35.3 million by 2030 (Huges, 2015). Over the same period, the GDP is expected to grow to between US$ 1501 and 1641 billion. This is a growth rate of approximately 1.4% per year in terms of population and approximately 4.6% per year for the GDP between 2015 and 2030. Thus, the GDP per person is expected to increase by approximately 3.1% per year on average within the same period.

Within the last 25 years, the KSA's oil production rose by 74% while the domestic energy consumption rose by 208% in the same timeframe (EIA, 2015). Based on the available data, the domestic share energy consumption grew from 21% to 37% over that period.

3.2. Power sector

Currently, the KSA has a single vertically integrated electricity company, the Saudi Electricity Company (SEC), which owns most of the generation, all of the transmission, and virtually all of the distribution assets; an exception is in the industrial city of Yanbu, where Marafiq (a private integrated utility company) is responsible for power generation, transmission, and distribution (Jeddah Economic Gateway, 2015). Also, a considerable number of private generators and Independent Power Producers (IPPs) exist that produce power and sell their generation to SEC or supply to isolated non-grid connected loads. A few large industrial consumers (e.g., Saudi Aramco) have their own captive generation, which is used to feed a substantial portion of their own load (Jeddah Economic Gateway, 2015).

By the end of 2014, the total available capacity of electricity generation power plants was great than 78 GW (SEC, 2014, ECRA, 2006). Over the last two decades, the power plant fleet capacity experienced an average growth rate of 5.7% per year. Over the last ten years, the installed power plant capacity doubled while it tripled over the last two decades. In 2014, 46% were Gas Turbines (GT, or Open Cycle GT), 39% Steam Turbines (ST), 14% Combined Cycle Gas Turbines (CCGT), and 1% distributed generation. Between 2000 and 2014, the electric demand developed from 126 to 304 TWh, while the peak demand has grown from 22 GW to 60 GW. This amounts to a growth rate of 6.5% for total electricity demand and 7.4% for peak demand.

3.3. Energy prices

The KSA and other Gulf Cooperation Council (GCC) member states are well known for subsidizing the cost of domestic energy, including electricity and fuel, but also other utilities, such as water (Hagihara, 2013). During the last three decades, several price changes for electricity were implemented. In 1974, the electricity price was 30 Halalas/kWh, which reduced to about 15 Halalas/kWh (4 US$-cent/kWh) in 1984. The next domestic retail fuel price change was implemented in 2011, when different prices for different sectors were introduced. Since then, the price for residential customers is 12 Halalas/kWh (3.2 US $-cent/kWh) all year long without seasonal or time-of-use (ToU) variations. Since 2011, industrial ToU rates have been available and are between 14 and 15 Halalas/kWh (3.7–4 US$-cent/kWh). The most recent change was implemented in December 2015, when domestic fuel, electricity, and water prices were increased (Mills, 2016). Since then, the utility sector has had to pay $6.35 for a barrel of Arab Light, $4.40 for a barrel of Arab Heavy, $3.80 for a barrel of heavy fuel oil, and $14.00 for a barrel of diesel, reflecting increases of 50%, 65%, 83%, and 313%, respectively from previous levels.

In the years between 1990 and 2002, fuel prices were below $1/gallon, while over the last decade fuel prices were on average around $2/gallon. For the purpose of this research, the World Bank fuel-price forecast was used as the international fuel-price reference (World Bank, 2016). Current domestic retail fuel price setting does not reflect international wholesale fuel prices as a reference (or percentage). We assume that an upcoming fuel-price reform will correct this accordingly.

In October 2014, a general opinion was that crude prices would remain quite constant at around $17/million BTU (MMBTU), but the last three years have proven that forecasting crude prices is not easy, if even possible (World Bank, 2016). Technological developments in shale gas, shale oil, or gas hydrate might be envisioned, but it is very difficult to predict how the global industry as well as large oil players in Kuwait, Iran, and Iraq will participate in the future production. Also, overall energy consumption in large countries such as China, the United States (U.S.), and India will be unpredictable over time. The U.S. Energy Information Administration (EIA) projects three different international fuel-price scenarios (low, medium, or reference, and high); the medium projection is used for our purposes (EIA, 2015).

4. Fuel-price reform policies

Following four years of relative stability at around US$ 100/barrel, oil prices have declined sharply since June 2014 (World Bank, 2015). At these times of low oil prices, fuel-price reforms are a major topic of consideration in oil-producing nations where budgets are facing increased stress. Indeed, energy subsidies have recently been at the center of research in academia (Griffiths, 2017, Moshiri, 2015, Guillaume and Zytek, 2010, Dartanto, 2013, Krane and Hung, 2016, Fattouh and Sen, 2016, Benes et al., 2015, Lahn, 2016) as well as by the International Monetary Fund (IMF, 2008, 2013, 2015, 2014), the World Bank (World Bank, 2010), and the International Energy Agency (IEA, 2010, 2011). These reforms, along with other fiscal and economic reforms, are needed to safeguard medium to long-term sustainability of public finances, support fiscal diversification, and remove misallocations and distortions in the economy (Deutsche Bank Research, 2015, Lipton, 2013).

Overviews of the research on fuel-price policies are provided by various publications (Griffiths, 2017, Krane and Hung, 2016, Fattouh and Sen, 2016, Benes et al., 2015, IMF, 2015, GIZ, 2015), with developments in international energy markets including the rise of shale oil and the associated oil price decline, global concern for climate change and sustainability, and increased diversification of energy sources (including renewables) being defined as the most prominent global factors affecting Middle Eastern and North African energy policies (Griffiths, 2017). Therefore, it is not surprising that fuel-price reforms are under way, as the consequences of energy subsidization in the Middle East and North Africa include the formation of energy-intensive industries that depend on low-cost energy for competitiveness, lack of incentives for efficiency improvements in the industrial and utility sectors, accelerated growth in demand for primary fuels and electricity, fuel shortages, unequal distribution of benefits with the richer segments of the population benefiting disproportionally, growth in carbon emissions, and a rising and often unsustainable fiscal burden (Griffiths, 2017, Fattouh and Sen, 2016, IMF, 2014, Fattouh and El-Katiri, 2013). Consequently, some GCC countries have implemented deregulation (Fattouh and Sen, 2016, Deutsche Bank Research, 2015). In January

2015, Abu Dhabi increased prices for water and electricity. In August 2015, the United Arab Emirates deregulated petrol and diesel prices. While still set by the government on a monthly basis, domestic retail fuel prices have been linked to global market prices. Kuwait, where parliamentary influence over energy policy has made the social contract more difficult to adjust than in the rest of the GCC (Griffiths, 2017), elected to take a more gradual approach to cutting fuel subsidies as compared to the United Arab Emirates, starting in 2016 (Deutsche Bank Research, 2015). Interestingly, Kuwait's power generation inadequacies are as much a consequence of the low prices charged by the utilities as of the insufficiencies of its infrastructure (Oxford Institute for Energy Studies, 2014). Overall, in the GCC all six monarchies (KSA, United Arab Emirates, Kuwait, Oman, Qatar, and Bahrain) increased prices on transportation fuels between 2015 and 2016, some have raised residential prices on electricity and water (the United Arab Emirates, Qatar and Bahrain for non-citizens only, KSA only for high consumption brackets), and most have reduced water and electricity subsidies for businesses (KSA, United Arab Emirates, Qatar, Oman, and Bahrain) (Krane and Hung, 2016).

Fuel-price reform was introduced in Egypt (Gaber, 2014) in 2014 as a decisive first step in reducing the country's energy subsidies but it is still a work in progress (Griffiths, 2017). The reform efforts in Morocco have largely eliminated price controls across energy products; Jordan has done very well with petroleum product related reforms but is still facing financial burdens from remaining electricity subsidies (Verme, 2016). Both countries have been relatively successful in achieving reform measures without causing serious unrest through context-appropriate implementation of accepted practice measures that include adequate planning, gradual price adjustments, consensus building, communication strategies, provision of adequate direct and indirect mitigation measures, and sufficient breadth of reform (Griffiths, 2017, IMF, 2014, Fattouh and El-Katiri, 2013, Whitley and van der Burg, 2015). Lebanon and Tunisia are countries with negligible oil resources that have come under price reform pressure; regular price changes have become the norm and subsidies have more or less been capped or eliminated (GIZ, 2010). In Iran, the government embarked on an aggressive energy price reform by removing energy subsidies and providing cash handouts to all Iranian households in 2010 (Moshiri, 2015).

The thought-provoking question that remains is how the largest economy in the GCC, and one of the world's largest per-capita energy consumers, will further approach the issue of fuel-price reforms (following the first reforms and in the face of extremely low domestic retail fuel price levels in December 2015 (Krane and Hung, 2016, Fattouh and Sen, 2016)). In Saudi Arabia, foreign exchange reserves including Sovereign Wealth Fund (SWF) resources are substantial and estimated to be in excess of US$ 500 billion. Yet fiscal pressures are profound, with a deficit of about US$ 90 billion annually or 18% of GDP in 2015 (Deutsche Bank Research, 2015). Taking money out of the SWF is not a sustainable practice. While Matar et al. (2014) model how to lower Saudi Arabia's fuel consumption and energy system costs without increasing end consumer prices, we believe that further price reforms must be assessed under future energy policy modeling scenarios, as initial fuel-price modifications have already taken place.

5. The model

5.1. Modeling approach and model description

In this paper, we pursue a modeling approach based on three foundations: i) generation expansion planning (GEP) optimization in terms of cost minimization; ii) multiple-scenario analysis of different fuel-price reforms; and iii) the OSeMOSYS. First, we employ a cost minimization approach in the following model to simulate capacity additions in the KSA power market over the period 2015 to 2030. Second, we utilize a multiple-scenario analysis application to model the different permutations of input parameters (mainly fuel-price changes) to quantify the level of price reform needed to achieve emissions reductions until 2030. Third, for the economic modeling, an improved version of OSeMOSYS is used (Howells et al., 2011). Developed by the renowned KTH Royal Institute of Technology in Stockholm, OSeMOSYS represents a very flexible and comprehensive MILP framework for long-term energy planning that is available on an open-source basis. As fuel prices are volatile and difficult to predict (EIA, 2015, World Bank, 2016), the focus of this paper is on assessing the minimum fuel cost required to reach a certain renewable energy penetration within the GEP period until 2030. In its base form, OSeMOSYS provides a test-bed for new energy model developments and system model applications, especially in developing countries. Its more advanced forms include added functionalities for prioritization of demand types, shifting demand, and storage options (Welsch et al., 2012), as well as reserve requirements and dispatching features (Welsch et al., 2014).

Groissböck and Pickl (2016) added significant model improvements to account for the impact of ambient temperature change on power generation output and efficiency, and add the possibility of a multi-objective function (adjustable weights on costs and emissions) to allow Pareto frontier assessments. For the purpose of this research, we added further model enhancements, predominantly: i) the option of allowing retirements of existing technologies (as about 50% of today's capacity is based on GT's), and ii) the feature of setting the renewable energy penetration to a specifiable maximum limit to make sure the obtained results are in line with the transmission infrastructure capabilities. Further equations were added to the model to consider retirements as well as an upper limit of renewable installations per year to make sure that the added renewable resources can be handled by the transmission grid.

5.2. Scenario description and assumptions

To guide policymakers and inform fuel-price reform, it is necessary to assess today's situation as well as possible changes. Therefore, we ran more than two hundred scenarios to assess impacts on the power generation fleet. For each scenario, the fuel price was adjusted annually by increasing the domestic retail fuel price by 10%–100% (in 10% increments) up to a level of 10–100% (in 10% increments) of the international wholesale fuel price by year. Fig. 1 shows how the domestic retail fuel prices are adjusted for an illustrative scenario where the fuel price is increased by 50% per year up to a maximum of 50% of the international wholesale fuel price. The domestic fuel-price ratios are not the same as ratios within the international wholesale fuel prices. This can have significant impact on GEP as, for example, the cost of heavy fuel oil (HFO) is lower than for natural gas. Having HFO too low would favor ST plants using HFO, while globally most utilities would favor (based on relatively low international wholesale fuel prices) CC plants fired by natural gas. Very low liquid fuel costs also do not incorporate purchase cost, handling fees, and other covered costs.

The analysis is impacted by the assumed capital expenditures (CAPEX) for the considered technologies and to a lesser extent by the O &M costs. CAPEX and O&M costs were compiled from one source to

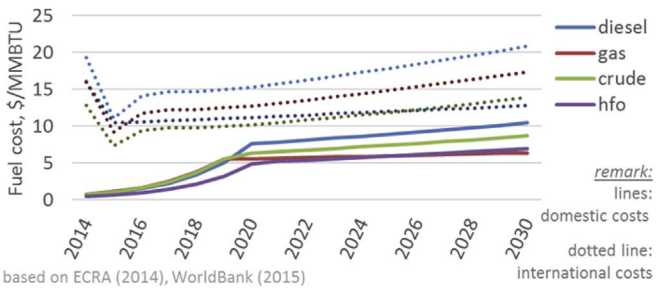

Fig. 1. Fuel costs scenarios +50%/a, limit at 50% of international fuel cost (reference case), 2014–2030.

ensure confidence about the cost differentials among the technologies (refer to Fig. 12 in the Appendix for core assumptions regarding capital costs and fixed annual O&M costs per technology) (Europe, 2014). Missing data for the years not provided are calculated based on linear interpolation.[2] Nevertheless, it is important to mention that the costs for renewables (mainly photovoltaic) are significantly above project costs seen in recent bids, making the model results here conservative. This conservative approach allows a margin for higher interconnection and integration costs as renewables might be further away from load centers and might require additional balancing infrastructure or costs.

In their analysis, Lahn and Stevens expect in a Business as Usual (BAU) scenario that energy demand will double by 2030 compared with 2011 (Lahn and Stevens, 2011). This represents a compound annual growth rate (CAGR) of 3.7% per year, which may seem optimistic based on recently realized growth. Nevertheless, as forecasting energy demand is not the focus of our analysis, we assume this growth rate for the entire planning period. It is well understood that fuel-price reform will impact on electricity prices, which in turn will impact electricity consumption. However, research suggests that residential price elasticity within the GCC is very low – the long run price elasticity of electricity demand for Bahrain, Kuwait, Oman, and Saudi Arabia is found to range from −0.16 to zero suggesting that the electricity consumers' response to price changes is very limited (i.e., demand is very price inelastic) (Atalla and Hunt, 2016) – and only a very high increase in price would result in a significant reduction in residential usage. Recent studies of the Middle Eastern region suggest that price increases alone will not substantially reduce energy consumption (Moshiri, 2015). Within the Middle Eastern countries, energy forecasting has tended to systematically overestimate energy reduction potential (Gately et al., 2012). Therefore, we assume that the growth projection provided by Lahn and Stevens is reasonable even with an expected upcoming fuel and electricity price increase.

While in general a discount rate is used to calculate today's value of future investments, the social discount rate is used for public projects, such as infrastructure (Zhuang et al., 2007). For example, the U.K. had a domestic social discount rate of 10% in 1969, 6% in 1989, and 3.5% in 2003. For this analysis, a base-case discount rate of 5% is assumed, and a sensitivity discount rate of 10% is used to assess the likely renewable energy capacity development. All scenarios are based on a minimum reserve margin of 10%. Renewable energy sources (RES) are assumed to have constant expected load carrying capability (ELCC) with 40% for PV, 10% for wind, and 80% for CSP, while conventional technologies are assumed to have an ELCC/capacity credit of 95% (Gusmao and Groissböck, 2015). ELCC represents the capability of providing incremental load compared with the added new generation capacity. The OSeMOSYS version used is not capable of considering ELCC's based on actual RES penetration. The selected ELCC values represent the low end of the expected ELCC's with high penetrations of PV, wind, and CSP, respectively. For more details about ELCC and the selected values, we refer to (Gusmao and Groissböck, 2015). For the simulations, the upper limit of renewable energy capacity addition is set at 10 GW per year as a specified increase over time to consider a measured growth in installation. This allows the local electricity and project development companies to gain skills and experience in building and operating renewable facilities and to ensure that the transmission infrastructure can support renewable resource integration (Cantner et al., 2016). Without this limitation, the optimization model would build unrealistic high levels (20 GW and more) within the first year of being economical. To avoid unrealistic model behavior and mimic the realized growth of renewables in other parts of the world, an exponential growth function is incorporated in our model for the KSA. We assume that it requires seven years for the full 10 GW cases to reach the maximum allowed renewable capacity addition. After the allowed maximum capacity is reached, this value stays constant over the remaining period of the evaluation. This is a simplified approach where worldwide PV capacities and requirements are not considered in detail. Equation (1) shows how the exponential growth function is used within the model.

$$Cap(t) = actCap \cdot e^{(targetCap - actCap)^{\frac{1}{n}} \cdot t} \quad (1)$$

where *Cap(t)*: capacity in year t, *targetCap*: target capacity (in GW), *actCap*: current available capacity (in GW), *n*: years between current capacity and target capacity (in years), *t*: years ahead.

The objective function must meet COP21 and following climate initiatives targeting long-term CO_2 reductions already covered in Welsch et al. (2012). As the fuel price is subsidized initially, also the emissions penalty is considered as subsidized. The level of emissions subsidy depends on the ratio assumed fuel price vs. international wholesale fuel price in the respective year. Therefore, the objective function of the model utilized in this paper includes total system costs (capital spending, fuel costs, and fixed and variable maintenance costs) plus the cost of repairing damage caused by the released emissions (see equation (2)).

$$\min \begin{pmatrix} \sum_{y=1}^{Y} \sum_{r=1}^{R} tCost[y, r] + \\ \sum_{y=1}^{Y} \sum_{t=1}^{T} \sum_{r=1}^{R} tPenalty[y, t, r] \end{pmatrix} \quad (2)$$

where *tCost* is the annual discounted cost, *tPenalty* is the cost of repairing damage based on caused emissions, *y* is the year, *t* is the time slice within a year, R is the region to be considered within the objective function.

In this analysis, global emissions (carbon dioxide and methane) and local emissions (nitrogen oxides, sulfur dioxide, volatile organic compounds, and fine particles) are quantified and considered simultaneously. The considered indicator (quality enhanced life days, QELD) was derived from MciLvaine (2014) and is developed based on an indicator provided by the U.S. Environmental Protection Agency (EPA): the “lesser quantity emissions rates” (LQER). According to the EPA, the cost for a ton of CO_2 emission can be valued at US$50. Based on this MciLvaine (2014) developed the improved indicator “quality enhanced life days,” which indicates how many days of life are lost based on emissions, by estimating values for $PM_{2.5}$, SO_2, VOC, NO_x, Methane, and CO_2 (see Table 1). QELD is a simple and useful approach as it represents a methodology to consider global and local air pollutants simultaneously. In our discussion of the results, we stress the relationship between types of capital expenditures and emissions.

Especially around renewable energy and energy efficiency improvement programs, the topic of “job creation” is omnipresent (Van der Zwaana et al., 2013). For our purposes, and to be conservative, only direct job creation is considered; indirect and induced jobs are not estimated. The number of net incremental jobs added to the KSA economy is calculated based on an expansion plan for the existing power plant fleet as well as retirements. Current estimates of the jobs required for conventional power generation amount to 0.2 jobs/GWh, compared to 0.6 jobs/GWh for PV, 1.0 jobs/GWh for wind, and 1.9 jobs/GWh for CSP (UKERC, 2014). These estimates should be used with caution as they vary from country to country and over time.

6. Results

This section presents and discusses the results of the modeled scenarios. We modeled the evolution of the power capacity expansion in the Kingdom of Saudi Arabia over the period 2015 to 2030 under different fuel-price reforms in a multiple-scenario analysis approach.

In Figs. 2–9, the first block represents the most different fuel-price assumptions. Scenario Run C000 reflects domestic retail fuel prices. Scenario C001 incorporates medium international fuel-price expectations, C002 incorporates low international fuel-price expectations, and

[2] e.g. if values for 2010 and 2015 are available, and 2012 should be estimated it would be $\{2012\} = \left(\frac{\{2015\} - \{2010\}}{2015 - 2010}\right)(2012 - 2010)$.

Table 1
Issued emission (MciLvaine, 2014).

Emission	CO_2 equivalent (in ton)	Qeld lost (per ton)
$PM_{2,5}$	1000	100
SO_2	100	10
VOC	100	10
NO_X	100	10
CH_4 (METHANE)	23	2.3
CO_2	1	0.1

The first run in each block considers a maximum allowed fuel-price cap of 10% of the medium international wholesale fuel price; the second allows increases up to 20% of the medium international wholesale fuel price; and so forth.

Fig. 2 shows that, with QELD costs included and applying a 5% discount rate in the illustrated fuel-price scenarios, the **renewable penetration** (mainly wind and PV) can reach up to 75% of the available capacity (or up to 30% on electricity required) in 2030. If emissions penalties are not included as additional costs, 50% of available

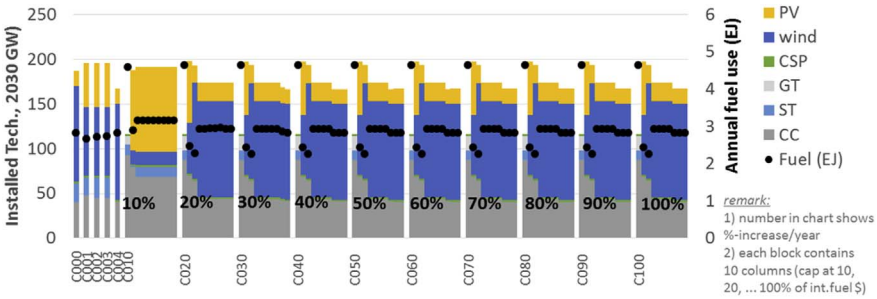

Fig. 2. Installed generation capacity in 2030, in % (with QELD costs, 5% DR).

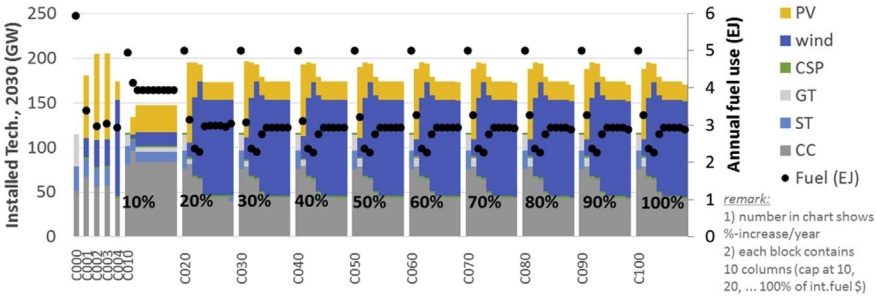

Fig. 3. Installed generation capacity in 2030, in % (with QELD costs, 10% DR).

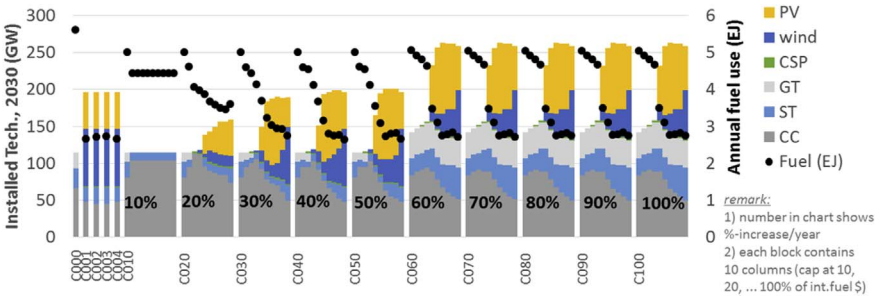

Fig. 4. Installed generation capacity in 2030, in % (without QELD costs, 5% DR).

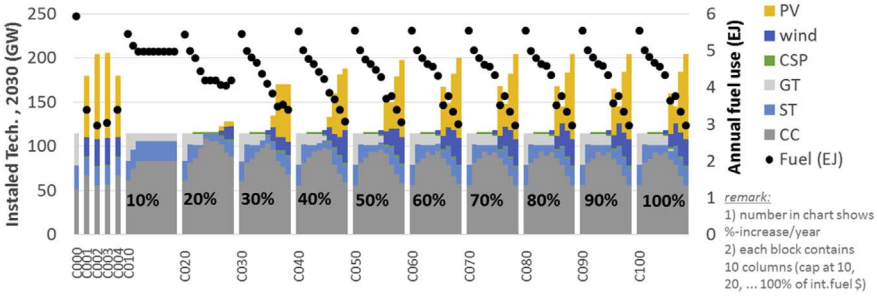

Fig. 5. Installed generation capacity in 2030, in % (without QELD costs, 10% DR).

C003 reflects high international fuel-price expectations. Other scenarios represent cases with fuel-price changes and limited fuel-price change compared to the expected medium fuel-price scenario. The first block allows for a 10% increase per year starting from current domestic retail fuel prices; the second allows for a 20% increase per year; and so forth.

capacity will still be from renewable technologies (Fig. 3). The remaining generation technologies will be a mix of CC, ST, and GT and represent 25% and 50% of capacity. If emissions penalties are not considered and no renewables are added, conventional technologies will increase to about 120 GW in 2030 (Fig. 4). This would double the

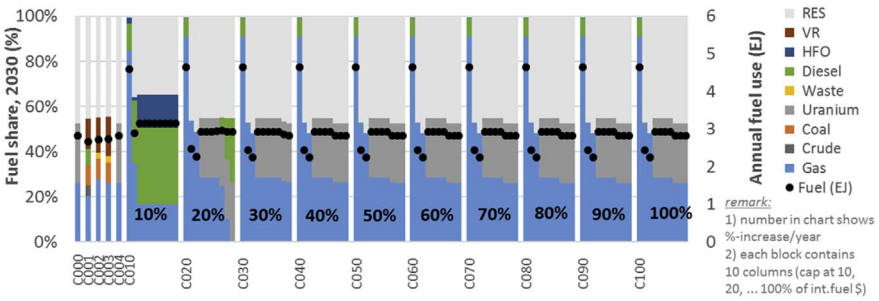

Fig. 6. Fuel use in 2030, in % (with QELD costs, 5% DR).

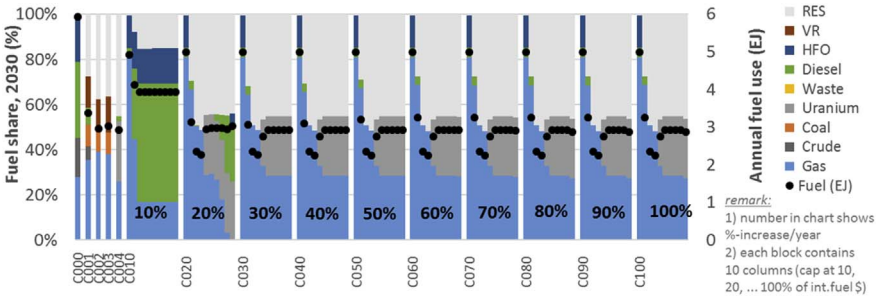

Fig. 7. Fuel use in 2030, in % (with QELD costs, 10% DR).

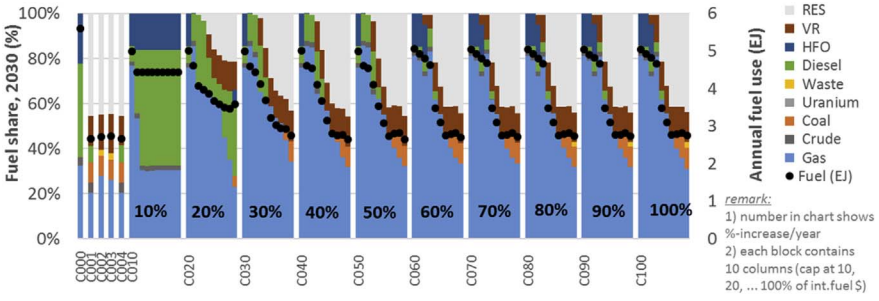

Fig. 8. Fuel use in 2030, in % (without QELD costs, 5% DR).

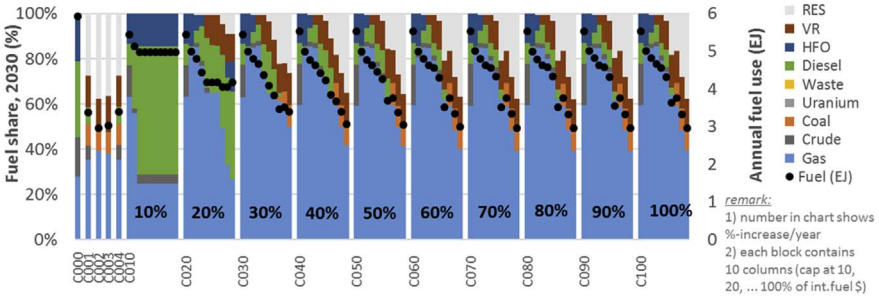

Fig. 9. Fuel use in 2030, in % (without QELD costs, 10% DR).

conventional capacity within 15 years relative to 2015. Alternatively, when implementing renewable technologies, conventional technologies could decrease to about 40 GW in 2030, while renewable capacity increases significantly to about 130 GW in all scenarios (Figs. 4 and 5). The increase of renewable in all scenarios is an unavoidable result of minimizing costs based on emissions. As soon as emissions penalty costs are considered, all results with domestic retail fuel price above 20% of international wholesale fuel prices (on average about 2.8 $/MMBTU) result in comparable solutions. If emissions penalties/costs are not considered, a domestic retail fuel price that is 60% of international level or above (on average about 8.3 $/MMBTU) results in similar outcomes. From these findings, it becomes apparent that 60% of international fuel-price costs could be a primary recommendation for fuel-price setting if emissions penalties are not considered. If emissions penalties are considered, a domestic retail fuel price that is 20% of international wholesale fuel prices would be enough to optimize the utility generation market. Considering emissions penalties favors wind installation while not considering emissions penalties favors PV. This is the result of the high capacity factor of wind where it produces twice as much electricity as PV does.

Figs. 6 and 7 represent **fuel usage** in 2030 considering emissions penalties (given as a percentage of total fuel demand), while Figs. 8 and 9 show the fuel usage without considering emissions penalties. All scenarios considering international wholesale fuel prices (scenarios C001 to C003, with and without emission penalty) show significant use of VR (i.e., the bottom product from the vacuum distillation unit in the refining process) and coal. The emissions penalty cases show uranium (used in ST plants) and natural gas as the main source of fuel in 2030. The no-emissions penalty cases show natural gas as the main fuel, significant amounts of VR and coal, and notably no uranium used in any installed ST plants. The scenarios with a 10% fuel-price increase rate per year (scenarios C010 to C019) maintain diesel and HFO as main fuel

in the generation mix. With fuel prices increasing at a 30–40% rate per year, the fuel share does not change significantly. The increase in fuel usage in these cases is based on adding nuclear power plants (using ST plants), which have lower efficiencies compared with CC plants. Renewables are modeled with an efficiency comparable to ST, so the fuel displaced by introducing renewables indicates the fuel otherwise required to be supplied. The results show that the domestic fuel-price scenario C000 has a significant share of diesel consumption, whereas the low international fuel-price scenario C002 and the high international fuel-price scenario C003 show coal and VR consumption. When considering emissions penalties, diesel is only part of the solutions where a 10% increase is considered. If emissions penalties are not considered an increase of up to 50% of international (on average about 11.0 $/MMBTU) is necessary to eliminate diesel consumption. The domestic fuel-price scenario C000, as well as the international fuel-price scenarios (C001-C004), reveal no significant share of liquid fuels while VR and coal consumption are significant. With an increase to less than 50% of international fuel costs, diesel is a significant part of the entire fuel mix. Fuel-price changes of 40% per year or more do not substantially impact the total fuel use.

Depending on the optimization scenario, the KSA's domestic fuel demand changes from between 3500 and 4000 PJ/year to between 2750 and 5600 PJ/year from 2015 to 2030. We find that considering QELD costs does reduce fuel demand by 500 PJ/year immediately, as fuel pricing alone does not send the required signal for most environmental friendly electricity generation. Most scenarios considering emissions penalties result in a fuel demand in 2030 of between 2750 and 3150 PJ/year. With emissions penalties there are two trends: one to decrease the fuel demand during the entire planning period, and the other is to increase of fuel demand after 2025. This effect is based on discounting future costs. Confirmed by related research is the finding that coal is not part of a domestic energy environment where COP21 is deemed binding (Matar et al., 2016).

CSP is chosen as a technology in none of the scenarios within the planning period until 2030. This is because it is assumed that the entire KSA grid is a well-interconnected grid, all fuels are available everywhere, and transmission between the areas is possible (a high-level assumption). Depending on the scenario, 50% of PV or wind can be reached considering emissions costs, and about 50% for PV and 40% for wind without considering emissions costs subject to managing resource variability issues (Elshurafa and Matar, 2017).

We also evaluated the impact of a 10% discount rate on the obtained results compared to the 5% rate. The results with emissions penalties do not show significant differences as the value of the health impact outweighs the additional discounting effect; again, about 20–30% of international wholesale fuel prices are sufficient to trigger renewable investments. The scenarios without emissions penalties demonstrate similar PV potential, but only about 20% of wind potential. Without emissions penalties, a fuel price of 70% of international wholesale fuel price (on average about 9.7 $/MMBTU) is necessary to achieve significant amounts of renewables. Interpreting the scenarios, we conclude that PV is better at lower fuel costs when replacing peak power generation, whereas wind is a better choice with higher fuel costs when replacing baseload power generation. Another study finds that 25% of PV is ideal from an operational perspective when not considering capital costs and assuming the currently low domestic retail fuel prices as well as the 2015 demand profiles (Elshurafa and Matar, 2017). An increase of domestic retail fuel prices might decrease the ideal PV operational penetration, as more expensive reserves have to be online, but would allow significant higher penetration from a fuel savings perspective (fuel costs usually amount to 70–90% of the total lifetime costs of a conventional generation technology).

Finally, Figs. 10 and 11 display within this assessment the **emissions** measured by the QELD (quality-of-life days) indicator and compares them to the capital requirements to estimate a Pareto frontier, that is, a state of optimal resource allocation from which it is impossible to make reallocations that improve any preference criterion (in our case QELD versus CAPEX) without impacting the other preference criterion. The overall maximum potential of QELD reduction until 2030 is estimated at around 25%; however, this would increase capital expenditure requirements more than four-fold. Furthermore, Figs. 10 and 11 show that a firstly significant decrease of emissions (dotted line), is followed by a more gradual decrease in emission reduction (dashed line). This suggests that 20% of the emissions can be reduced by an increased CAPEX spending of 250–290% depending on the considered discount rate, whereas higher emissions reductions require significantly more CAPEX. Especially in the light of an expected electricity demand growth of 3.7% (CAGR) until 2030, even a 20% reduction represents a substantial challenge.

7. Conclusions

The core contribution of this research was to model the KSA's future power generation expansion plan and renewable energy penetration over the next 15 years (2015–2030) and quantify the fuel-price reform needed in the KSA to attain certain energy policy goals in terms of emissions reduction, liquid-fuel replacement, incremental employment, and renewable energy penetration. The findings show that when emissions are priced, already at 20% of international wholesale fuel prices, a shift from fossil-fuel-based power generation expansion to renewable power generation expansion is predicted in the KSA up to a renewable penetration (predominantly wind and PV) of 75% of available capacity and 30% of energy production in 2030. The scenarios that do not consider emissions penalties show more variance in results, as fuel costs have a higher impact. Lower fuel prices result in higher PV penetration and higher fuel prices result in higher wind penetration. This implies that within scenarios of lower fuel prices, the value for capacity credit (or ELCC) is more important than the fuel savings, while the reverse holds for higher fuel prices. A broader discussion about capacity credit and the chosen values can be found in Gusmao and Groissböck (2015). Not pricing for emissions requires a fuel price of at least 50% of the international wholesale fuel price to see significant renewable technologies in the final generation mix. A fuel price that is 50% of the corresponding international wholesale fuel price (on average about 6.9 $/MTBU) would result in 30% of total power capacity from renewables, while a fuel price that is 60% of the corresponding international wholesale fuel prices (on average about 8.3 $/MTBU) would result in approximately 50% of total power capacity from renewable technologies by 2030. These scenarios would still have some deadweight losses, that is, costs to society created by market inefficiency occurring because fuels within the KSA market are not correctly valued (independent of whether they were covering domestic fuel exploration and production costs) (IEA, 2010). However, such prices would be in-line with the vision of the government to rationalize fuel prices on a step-wise basis within the next five years (Krane and

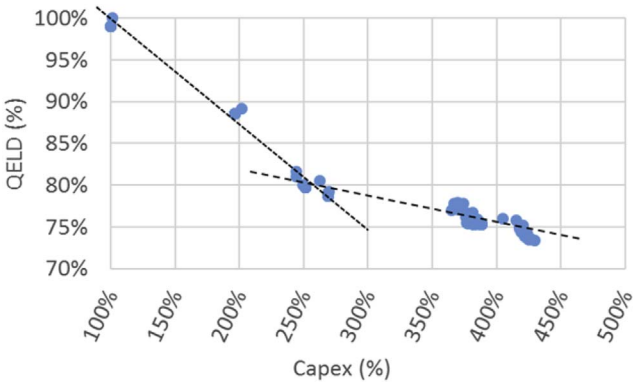

Fig. 10. QELD reduction vs. Capex requirements (with QELD costs, 5% DR).

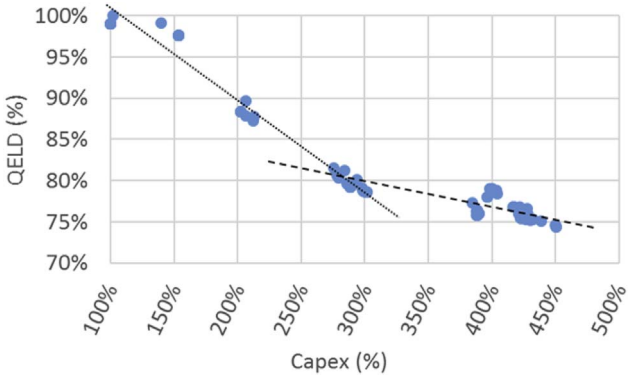

Fig. 11. QELD reduction vs. Capex requirements (with QELD costs, 10% DR).

Hung, 2016). Increased fuel prices would encourage efficiency as well as alternative power generation technologies, while the suggested fuel-price levels would still be responsive to the low-income local population. The overall level of total renewables added depends on: a) the renewable policy and strategy of the KSA, and emissions pricing; b) grid quality and transmission infrastructure limits; and most importantly, c) the pace of fuel-price reform and price caps as modeled in this multiple-scenario analysis.

It remains to be seen how the Kingdom of Saudi Arabia, the largest economy in the Gulf Cooperation Council and one of the world's largest per-head energy consumers, will approach the issue of further fuel-price reforms. First actions in December 2015 highlight that fuel-price reform, in one form or another, can be expected. A starting point within the process of fuel-price liberalization could be that utility providers will be forced to consider international wholesale fuel prices for project assessment as well as for calculating the dispatch of power plants based on merit order. In a transition period, payments could be based on domestic retail fuel prices, which could be based on production cost as well as overhead fees. This approach would avoid overcharging and thus burdening domestic utility companies while ensuring power plant fleet efficiency. Low current levels of fossil fuel prices can be seen as an opportunity to adjust domestic retail fuel prices upward and narrow the differential (Benes et al., 2015). Overall in the GCC, four out of six countries have raised residential prices for electricity and water (UAE, Qatar, Bahrain for non-citizens only, and KSA only for high consumption brackets) between 2015 and 2016; five of the six have reduced water and electricity subsidies for businesses (KSA, UAE, Qatar, Oman, and Bahrain) (Krane and Hung, 2016). Compared to the KSA, the situation in the UAE and other GCC countries is easier to change because public transportation alternatives, higher income levels, and the greater presence of expatriates make fuel price reforms less politically problematic.

8. Further research

In this research, we quantified how further fuel-price reform can help achieve certain energy policy goals in terms of emissions reduction, liquid-fuel replacement, incremental employment, and renewable energy penetration. Further research can explore how to implement the proposed phased pricing increases, to gain acceptance among the population, and to protect the poorer members of the community. Future research is also needed to evaluate demand reduction potential based on more stringent energy efficiency standards for buildings and lighting within the GCC countries, including the KSA. Finally, the price and income elasticity of electricity demand as well as implications of fuel-price changes on overall GDP, including the utility, industry, and transportation sectors, clearly deserves monitoring and further research.

Disclaimer

The views expressed herein are those of the authors solely.

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Appendix

technology	year	capex ($/kW)	fixed O&M ($/kW*y)	var. O&M ($/MWh)	electric eff. (%)
ST Nuc Gen. III	*2015*	5.651	119	3,2	37%
	2020	5.555	117		
	2025	5.395	113		
	2030	5.236	110		
GT Gas & Diesel	*2015*	702	21	14,0	37%
	2020	702	21		
	2025	702	21		
	2030	702	21		
GT Crude	*2015*	1.047	27	17,6	37%
	2020	1.047	25		
	2025	1.047	24		
	2030	1.047	23		
CC Gas & Diesel	*2015*	1.085	27	2,6	52%
	2020	1.085	27		
	2025	1.085	27		
	2030	1.085	27		
CC Crude	*2015*	1.430	36	6,1	48%
	2020	1.430	36		
	2025	1.430	36		
	2030	1.430	36		
ST (pulv. Coal & VR)	*2015*	2.043	51	4,6	43%
	2020	2.043	51		
	2025	2.043	51		
	2030	2.043	51		
PV fixed	*2015*	1.137	19	2,6	100%
	2020	1.022	17		
	2025	919	16		
	2030	817	14		
PV 1-axis tracking	*2015*	1.628	24	2,6	100%
	2020	1.405	21		
	2025	1.271	19		
	2030	1.137	17		
CSP no TES	*2015*	6.449	258	10,2	100%
	2020	5.747	230		
	2025	5.108	204		
	2030	4.470	179		
CSP 6h TES	*2015*	7.758	465	15,3	100%
	2020	6.781	407		
	2025	6.091	365		
	2030	5.402	324		
Wind Onshore	*2015*	1.756	45	5,1	100%
	2020	1.724	41		
	2025	1.692	39		
	2030	1.660	37		
ST Gas & Diesel	*2015*	1.400	29	4,7	34%
	2020	1.400	29		
	2025	1.400	29		
	2030	1.400	29		
ST Crude	*2015*	1.760	29	4,7	34%
	2020	1.760	29		
	2025	1.760	29		
	2030	1.760	29		
ST Waste	*2015*	6.900	29	4,7	36%
	2020	6.900	29		
	2025	6.900	29		
	2030	6.900	29		

Source: ETRI 2014 (Europe, 2014)

Fig. 12. Capital cost, O&M, efficiency for all considered generation technologies (2013–2030) (Europe, 2014).

References

Aliyu, A.S., Ramli, A.T., Saleh, M.A., 2013. Nigeria electricity crisis: power generation capacity expansion and environmental ramifications. Energy 61, 354–367.

Alyousef, Y., Stevens, P., 2011. The cost of domestic energy prices to Saudi Arabia. Energy Pol. 39, 6900–6905.

Atalla, T.A., Hunt, L.C., 2016. Modelling residential electricity demand in the GCC countries. Energy Econ. 59, 149–158. http://dx.doi.org/10.1016/j.eneco.2016.07.027.

Augutis, J., Marisauskas, L., Krikstolaitis, R., 2015. Energy mix optimization from an energy security perspective. Energy Convers. Manag. 90, 300–314. http://dx.doi.org/10.1016/j.enconman.2014.11.033.

Bazilian, M., Rice, A., Rotich, J., Howells, M., DeCarolis, J., Macmillian, S., Brooks, C., Bauer, F., Liebreich, M., 2012. Open Source software and crowdsourcing for energy analysis. Energy Pol. 49, 149–153. http://dx.doi.org/10.1016/j.enpol.2012.06.032.

Becerra-Lopez, H.R., Golding, P., 2008. Multi-objective optimization for capacity expansion of regional power-generation systems: case study of far west Texas. Energy Convers. Manag. 49, 1433–1445.

Benes, K., Cheon, A., Urpelainen, J., Yang, J., 2015. Low Oil Prices: An Opportunity for Fuel Subsidy Reform. Columbia School of International and Public Affairs Available from: http://energypolicy.columbia.edu/sites/default/files/energy/Fuel%20Subsidy%20Reform_October%202015.pdf visited site July 14th 2017.

BP, 2014. BP Statistical Review of World Energy June 2014. BP June 2014.

Brand, B., Missaoui, R., 2014. Multi-criteria analysis of electricity generation mix scenarios in Tunisia. Renew. Sustain. Energy Rev. 39, 251–261.

Cantner, U., Graf, H., Herrmann, J., Kalthaus, M., 2016. Inventor networks in renewable energies: the influence of the policy mix in Germany. Res. Pol. 45 (6), 1165–1184. http://dx.doi.org/10.1016/j.respol.2016.03.005.

Chaudry, M., Jenkins, N., Qadrdan, M., Wu, J., 2014. Combined gas and electricity network expansion planning. Appl. Energy 113, 1171–1187.

Dartanto, T., 2013. Reducing fuel subsidies and the implications on fiscal balance and poverty in Indonesia: a simulation analysis. Energy Pol. 58, 117–134.

Deutsche Bank Research, 2015. Subsidy Cuts in the UAE: A Model for the GCC? Deutsche Bank Research August, 2015.

Dhakouani, A., Gardumi, F., Znouda, E., Bouden, C., Howells, M., 2017. Long-term optimisation model of the Tunisian power system. Energy 141, 550–562. https://doi.org/10.1016/j.energy.2017.09.093.

ECRA, 2006. Updated Generation Planning for the Saudi Electricity Sector. Electricity & Cogeneration Regulatory Authority Available from: http://www.ecra.gov.sa/pdf/longtermgenerationplanningforsaudielectricitysectorstudy.pdf visited site on November 11th 2016.

EIA, 2015. Saudi Arabia. US Energy Information Administration Available from: http://www.eia.gov/countries/country-data.cfm?fips=sa visited site on December 17th 2016.

Elshurafa, A.M., Matar, W., 2017. Adding solar PV to the Saudi power system: what is the cost of intermittency? Energy Trans. 1 (2), 1–9. http://dx.doi.org/10.1007/s41825-017-0002-7.

English, J., Niet, T., Lyseng, B., Palmer-Wilson, K., Keller, V., Moazzen, I., Pitt, L., Wild, P., Rowe, A., 2017. Impact of electrical intertie capacity on carbon policy effectiveness. Energy Pol. 101, 571–581. http://dx.doi.org/10.1016/j.enpol.2016.10.026.

Europe, 2014. ETRI 2014, Energy Technology Reference Indicator Projections for 2010-2050. European Commission, Joint Research Centre Institute for Energy and Transport Available from: https://setis.ec.europa.eu/system/files/ETRI_2014.pdf visited site on July 15th 2016.

Fairuz, S.M.C., Sulaiman, M.Y., Lim, C.H., Mat, S., Ali, B., Saadatian, O., Ruslan, M.H., Salleh, E., Sopian, K., 2013. Long term strategy for electricity generation in Peninsular Malaysia – analysis of cost and carbon footprint using MESSAGE. Energy Pol. 62, 493–502.

Farnoosh, F., Lantz, F., Percebois, J., 2014. Electricity generation analyses in an oil-exporting country: transition to non-fossil fuel based power units in Saudi Arabia. Energy 69, 299–308. http://dx.doi.org/10.1016/j.energy.2014.03.017.

Fattouh, B., 2013. Summer Again: The Swing in Oil Demand in Saudi Arabia. The Oxford Institute of Energy Studies July 2013.

Fattouh, B., El-Katiri, I., 2013. Energy subsidies in the Middle East and North Africa. Energy Strat. Rev. 2 (1), 108–115. http://dx.doi.org/10.1016/j.esr.2012.11.004.

Fattouh, B., Sen, A., 2016. Striking the Right Balance? GCC Energy Pricing Reforms in a Low Price Environment. Oxford Institute for Energy Studies Available from: https://www.oxfordenergy.org/publications/striking-right-balance-gcc-energy-reforms-low-price-environment/ visited site on July 14th 2017.

Gaber, D.M., 2014. Latest developments and opportunities in the electricity sector in Egypt. In: Saudi Arabia Smart Grid Conference on Smart Grids and Green Energy.

Gately, D., Al-Yousef, N., Al-Sheikh, H.M.H., 2012. The rapid growth of domestic oil consumption in Saudi Arabia and the opportunity cost of oil exports foregone. Energy Pol. 47, 57–68.

GIZ, 2010. Fossil Fuel Prizes in the Arab World and the Fear of Reform. Deutsche Gesellschaft fuer Internationale Zusammenarbeit.

GIZ, 2015. Fuel Price Policies. Deutsche Gesellschaft fuer Internationale Zusammenarbeit.

Gonzales-Salazar, M.A., Venturini, M., Poganiety, W.R., Finkenrath, M., Kirsten, T., Acevedo, H., Spina, P.R., 2016. A general modeling framework to evaluate energy, economy, land-use and GHG emissions nexus for bioenergy exploitation. Appl. Energy 178, 223–249. http://dx.doi.org/10.1016/j.apenergy.2016.06.039.

Griffiths, St, 2017. A review and assessment of energy policy in the Middle East and North Africa region. Energy Pol. 102, 249–269. http://dx.doi.org/10.1016/j.enpol.2016.12.023.

Groissböck, M., Pickl, M., 2016. An analysis of the power market in Saudi Arabia: retrospective cost and environmental optimization. Appl. Energy 165, 548–558.

Guillaume, D., Zytek, R., 2010. The Economics of Energy Price Reform in the Islamic Republic of Iran. IMF Country Report No. 10/76. Middle East and Central Asia Department, Washington.

Gusmao, A., Groissböck, M., 2015. Capacity value of photovoltaic and wind power plants in an isolated Mini-grid in the Kingdom of Saudi Arabia. In: Saudi Arabia Smard Grid Conference, December 7th – 9th 2015, http://dx.doi.org/10.1109/SASG.2015.7449275.

Habib, M.A., Chungpaibulpatana, S., 2014. Electricity generation expansion planning with environmental impact abatement: case study of Bangladesh. Energy Procedia 52, 410–420.

Hagihara, J., 2013. Saudi Arabia's domestic energy situation and policy: focusing on its power sector. Kyoto Bull. Islam. Area Stud. 6, 107–135.

Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., Hughes, A., Silveira, S., DeCarolis, J., Bazillian, M., Roehrl, A., 2011. OSeMOSYS: the open source energy modeling system – an introduction to its ethos, structure and development. Energy Pol. 39, 5850–5870.

Huges, B.B., 2015. IFs Version 7.15. Frederick S. Pardee Center for International Futures Available from: http://pardee.du.edu/ visited site on December 18th 2016.

IEA, 2010. Analysis of the Scope of Energy Subsidies and Suggestions for G20 Initiatives. A Joint Report by IEA,WorldBank,OECD, and OPEC. International Energy Agency June 2010.

IEA, 2011. Development in Energy Subsidies. World Energy Outlook. International Energy Agency.

IMF, 2008. Fuel and Food Price Subsidies, Issues and Reform Options. International Monetary Fund, Washington.

IMF, 2013. Energy Subsidy Reform: Lessons and Implications. International Monetary Fund.

IMF, 2014. Subsidy Reform in the Middle East and North Africa: Recent Challenges and Progress Ahead. International Monetary Fund (IMF), Washington, D.C.

IMF, 2015. Energy Price Reforms in the GCC—What Can Be Learned From International Experiences?, Annual Meeting of Ministers of Finance and Central Bank Governors. International Monetary Fund (IMF), Washington, D.C.

Jeddah Economic Gateway, 2015. Sectorial Report on Saudi Arabia – Electricity. July 2015.

Krane, J., Hung, S.Y.E., 2016. Energy Subsidy Reform in the Persian Gulf: The End of the Big Oil Giveaway. Rice University's Baker Institute for Public Policy Available from: https://www.bakerinstitute.org/media/files/research_document/0e7a6eb7/BI-Brief-042816-CES_GulfSubsidy.pdf visited site on July 14th, 2017.

Lahn, G., 2016. Fuel, Food and Utilities Price Reforms in the GCC: A Wake-up Call for Business. Royal Institute of International Affairs, London.

Lahn, G., Stevens, P., 2011. Burning Oil to Keep Cool - The Hidden Energy Crisis in Saudi Arabia. Available from: http://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy%20Environment%20and%20Development/1211pr_lahn_stevens.pdf visited site on December 18th 2016.

Lienert, M., Lochner, S., 2012. The importance of market interdependencies in modeling energy systems – the case of the European electricity generation market. Electr. Power Energy Syst. 34, 99–113.

Lipton, D., 2013. Energy Subsidy Reform: The Way Forward. International Monetary Fund Report, May 29th 2016.

Mansouri, N.Y., Crookes, R.J., Korakianitis, T., 2013. A projection of energy consumption and carbon dioxid emissions in the electricity sector for Saudi Arabia: the case for carbon capture and storage and solar photovoltaics. Energy Pol. 63, 681–695.

Matar, W., Murphy, F., Pierru, A., Rioux, B., 2014. Lowering Saudi Arabia's Fuel Consumption and Energy System Costs without Increasing End Consumer Prices. KAPSARC Discussion Paper, March 2014.

Matar, M., Echeverri, R., Pierru, A., 2016. The prospects for coal-fired power generation in Saudi Arabia. Energy Strat. Rev. 181–190, 13–14. http://dx.doi.org/10.1016/j.esr.2016.004.

McLvaine, R., 2014. A new approach for evaluating energy choices. Electr. J. 72–79. http://dx.doi.org/10.1016/j.tej.2014.11.003.

Mills, R., 2016. The Energy Subsidies Dam Has Finally Broken in the Middle East. The National Available from: http://www.thenational.ae/business/energy/the-energy-subsidies-dam-has-finally-broken-in-the-middle-east visited site on April 22nd 2016.

Moshiri, S., 2015. The effects of the energy price reform on households consumption in Iran. Energy Pol. 79, 177–188.

Nerini, F.F., Dargaville, R., Howells, M., Bazilian, M., 2015. Estimating the cost of energy access: the case of the village of Suro Craic in Timor Leste. Energy 79, 385–397. http://dx.doi.org/10.1016/j.energy.2014.11.025.

Niet, T., Lyseng, B., English, J., Keller, V., Palmer-Wilson, K., Moazzen, I., Robertson, B., Wild, P., Rowe, A., 2017. Hedging the risk of increased emissions in long term energy planning. Energy Strat. Rev. 16, 1–12. http://dx.doi.org/10.1016/j.esr.2017.02.001.

OIES, 2015. A Brief Political Economy of Energy Subsidies in the Middle East and North Africa. The Oxford Institute for Energy Studies February 2015.

OPEC, 2016. Organization of Petroleum Exporting Countries. Available from: http://www.opec.org visited site on July 19th 2016.

Oxford Institute for Energy Studies, 2014. Price Reform in Kuwait's Electricity and Water Sector: Assessing the Net Benefits in the Presence of Congestion. Oxford Institute for Energy Studies August 2014.

Reuters, 2013. Saudis Say Fuel Subsidies Distort Economy, Must Be Cut. Thomson Reuters Available from: http://www.reuters.com/article/2013/05/07/saudi-energy-subsidies-idUSL6N0DO12P20130507 visited site on June 23rd 2016.

SEC, 2014. Annual Reports. Saudi Electricity Company Available from: http://www.se.com.sa/en-us/Pages/AnnualReports.aspx visited site on October 20th 2016.

Shahmohammadi, M.S., Yusuff, R.M., Keyhanian, S., Shakouri, H.G., 2015. A decision support system for evaluating effects of Feed-in Tariff mechanism: dynamic modeling of Malaysia's electricity generation mix. Appl. Energy 146, 217–229.

The World Factbook, 2017. Country Comparison of Electricity Consumption. Central Intelligence Agency Available from: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2233rank.html visited site on December 27th 2017.

Thiam, D.-R., Benders, R.M.J., Moll, H.C., 2012. Modeling the transition towards a sustainable energy production in developing nations. Appl. Energy 94, 98–108.

UKERC, 2014. Low Carbon Jobs: The Evidence for Net Job Creation from Policy Support for Energy Efficiency and Renewable Energy. UK Energy Research Center Available from: http://www.ukerc.ac.uk/publications/low-carbon-jobs-the-evidence-for-net-job-creation-from-policy-support-for-energy-efficiency-and-renewable-energy.html visited site on November 29th 2017.

UN, 2015. World Development Indicators. Available from: http://data.worldbank.org/data-catalog/world-development-indicators visited site on September 19th 2016.

UNFCCC, 2016. Paris Agreement - Status of Ratification. United Nations Framework Convention on Climate Change Available from: http://unfccc.int/paris_agreement/items/9444.php visited site on July 14th 2017.

Van der Zwaana, B., Camerona, L., Kobera, T., 2013. Potential for renewable energy jobs in the Middle East. Energy Pol. 60, 296–304. http://dx.doi.org/10.1016/j.enpol.2013.05.014.

Verme, P., 2016. Subsidy Reforms in the Middle East and North Africa Region: A Review. World Bank Group.

Walmsley, M.R.W., Walmsley, T.G., Atkins, M.J., Kamp, P.J.J., Neale, J.R., 2014. Minimizing carbon emissions and energy expended for electricity generation in New Zealand through to 2050. Appl. Energy 135, 656–665.

Welsch, M., Howells, M., Bazilian, M., DeCarolis, J.F., Hermann, S., Rogner, H.H., 2012. Modelling elements of smart grids - enhancing the OSeMOSYS (open source energy modelling system) code. Energy 46, 337–350.

Welsch, M., Deane, P., Howells, M., Gallachóir, B.Ó., Rogan, F., Bazilian, M., Rogner, H.H., 2014. Incorporating flexibility requirements into long-term energy system models - a case study on high levels of renewable electricity penetration in Ireland (2014). Appl. Energy 135, 600–615. http://dx.doi.org/10.1016/j.apenergy.2014.08.072.

Whitley, S., van der Burg, L., 2015. Fossil Fuel Subsidy Reform: From Rhetoric to Reality. New Climate Economy, London and Washington, DC.

Woertz, E., 2013. The Domestic Challenges in the Saudi Energy Market and Their Regional and Geopolitical Implications. NOREF Norwegian Peace Building Resource Center Policy Brief November 2013.

World Bank, 2010. Subsidies in the Energy Sector: An Overview. Background Paper for the World Bank Group Energy Sector Strategy, Washington. .

World Bank, 2015. The Great Plunge in Oil Prices: Causes, Consequences, and Policy Responses. Policy Research Note. The World Bank Group March 2015.

World Bank, 2016. Commodity Markets. World Bank Available from: http://www.worldbank.org/en/research/commodity-markets visited site on April 20th 2016.

Wu, J.-H., Huang, Y.-H., 2014. Electricity portfolio planning model incorporating renewable energy characteristics. Appl. Energy 119, 278–287.

Zhang, Q., Mclellan, B., Tezuka, T., Ishihara, K.N., 2013. An integrated model for long-term power generation planning toward future smart electricity systems. Appl. Energy 112, 1424–1437.

Zhuang, J., Liang, Z., Lin, T., De Guzman, F., 2007. Theory and Practice in the Choice of Social Discount Rate for Cost –Benefit Analysis: A Survey. Available from: http://www.seachangecop.org/sites/default/files/documents/2007%2005%20ADB%20-%20Theory%20and%20Practice%20in%20the%20Choice%20of%20Social%20Discount%20Rate.pdf visited site on November 25th 2016.